BBC RD 1996/5

Research and Development Report

EXPERIMENTAL SATELLITE BROADCAST OF EUREKA 147 DAB FROM SOLIDARIDAD 2

J.T. Zubrzycki, B.Sc.(Eng.), Ph.D., C.Eng., M.I.E.E.,
R.H. Evans, B.Sc.(Eng.),
P. Shelswell, M.A., C.Eng., M.I.E.E.,
M.A. Gama (Telecomunicaciones de Mexico), *and*
M. Gutierrez (Instituto Mexicano de Comunicaciones)

Research and Development Department
Policy and Planning Directorate
THE BRITISH BROADCASTING CORPORATION

EXPERIMENTAL SATELLITE BROADCAST OF EUREKA 147 DAB FROM SOLIDARIDAD 2

J.T. Zubrzycki, B.Sc.(Eng.), Ph.D., C.Eng., M.I.E.E., R.H. Evans, B.Sc.(Eng.), P. Shelswell, M.A., C.Eng., M.I.E.E., M.A. Gama (Telecomunicaciones de Mexico), *and* M. Gutierrez (Instituto Mexicano de Comunicaciones)

Summary

BBC Research and Development Department, in collaboration with Telecomunicaciones de Mexico and the Instituto Mexicano de Comunicaciones, has carried out highly successful test transmissions of the Eureka 147 Digital Audio Broadcasting (DAB) system in Mexico from the Solidaridad 2 satellite from 17 to 21 July 1995. This included tests of mobile reception conducted in the suburbs of Mexico City. Even though the DAB signal is very different from the usual signals handled by the satellite, it was transmitted without distortion, verifying the feasibility of satellite DAB for nationwide reception of CD quality radio by car listeners. The Solidaridad 2 was designed for telecommunications, based on Inmarsat C technology, operating at L-band to and from mobiles and at K_u*-band for the fixed earth-to-space/space-to-earth links. The L-band frequencies are just above those designated for DAB by ITU-R and so the availability of this satellite gave an excellent opportunity to test the Eureka 147 DAB system.*

Issued under the Authority of

Research & Development Department
Policy & Planning Directorate
BRITISH BROADCASTING CORPORATION

General Manager
Research & Development Department

EXPERIMENTAL SATELLITE BROADCAST OF EUREKA 147 DAB FROM SOLIDARIDAD 2

J.T. Zubrzycki, B.Sc.(Eng.), Ph.D., C.Eng., M.I.E.E., **R.H. Evans**, B.Sc.(Eng.),
P. Shelswell, M.A., C.Eng., M.I.E.E., **M.A. Gama** (Telecomunicaciones de Mexico), *and*
M. Gutierrez (Instituto Mexicano de Comunicaciones)

EXPERIMENTAL SATELLITE BROADCAST OF EUREKA 147 DAB FROM SOLIDARIDAD 2

J.T. Zubrzycki, B.Sc.(Eng.), Ph.D., C.Eng., M.I.E.E.,
R.H. Evans, B.Sc.(Eng.),
P. Shelswell, M.A., C.Eng., M.I.E.E.,
M.A. Gama (Telecomunicaciones de Mexico), *and*
M. Gutierrez (Instituto Mexicano de Comunicaciones)

1. INTRODUCTION

Satellite digital audio broadcasting (DAB) is an attractive option for broadcasters in many parts of the world. Over the past year a start has been made in transmitting DAB terrestrial services, with the London area of the United Kingdom now having five Single Frequency Network (SFN)[1] transmitters to serve it. The UK will have a 60% coverage in less than 2 years (1998). Countries that are very large, or those that are sparsely populated, may find it uneconomic to provide a complete terrestrial service. In these instances, there is a strong argument for using satellite services to obtain a large-area coverage. Also, there is a particularly good case for providing international services via satellites when access to terrestrial transmitters is not possible or feasable. Satellite broadcasting would then implement the European Union policy of 'broadcasting without frontiers'. It would also make multilingual broadcasting a particularly effective option, as DAB multiplexes are readily reconfigurable.

Methods for delivering radio programmes from satellites have been under discussion for many years. In the early days, there were studies of AM or FM transmissions and of using short wave frequencies,[1,2] but these were found to be impractical. There is now a general acceptance that digital techniques are best suited to the purpose, and that an L-band frequency is technically optimum.[2,3]

Part of the difficulty for introducing satellite sound broadcasting economically is that the link budget for mobile and portable reception is rather tight. To make satellite sound broadcasting a success, it is necessary to ensure that full use is made of all the improvements in technology; without them, the system would be marginal and, consequently, less likely to succeed.

The question of mobile use does not arise when considering satellite television broadcasting. Usually, dish antennas between 60 and 90 cm in diameter are used, fixed to the exterior of the house. But for sound broadcasting, mobile use becomes a major consideration; occupants of cars, coaches and lorries are perhaps bigger users of radio at some times of the day than are householders! Small antennas (not needing critical alignment) are the main requirement for the mobile radio listener. It is the difference between the use of antennas for the non-mobile television viewer on the one hand, and the regularly-mobile radio listener on the other, that makes the difference in the link budget for each system.

Even though satellite sound broadcasting offers only a small margin in the link budget, there are possibilities which may be exploited for offering practical systems that would provide a useful service.

2. BACKGROUND DISCUSSION

2.1 Listener's interests

Not all listeners necessarily demand a high quality of sound reproduction; ruggedness, access and reliability are often more important to them. The listener wants *programmes* to listen to, the technology provides a *means* to that end!

There are already several digital sound broadcasting systems available on satellites, including the ITU-R recommendation BO. 789.[4] These have not been a resounding success. Though there is some interest, the majority of the public have not taken up the new services with any enthusiasm. The new digital sound services are based on the 12 GHz television systems and so require a fairly large dish antenna. Most radio users require to move their radios around, for at least some of their day; restricted positioning of the set is not acceptable. Also, satellite radio receivers are more expensive; the majority of people do not wish to spend as much on radio receivers as they are prepared to pay for television sets – radios must, therefore, be reasonably cheap; as a corollary, there is a much larger potential market than for television, on a global scale.

2.2 Options

The existing analogue radio service has the advantage of having developed a common system, where virtually any radio receiver capable of using AM and FM

can be used anywhere in the world. This means that receivers can be made in quantity, cheaply. Currently, the use of digital signals for terrestrial radio broadcasting is undertaken using a single worldwide standard, the Eureka 147 system. However, there are other proposals which are being considered, especially in the USA.

A system that can make optimum use of a satellite channel may not be the one that would be chosen as suitable for terrestrial use. Clearly, a common system is desireable if cheap receivers are to be made, even if a less efficient method of satellite transmission were finally to be used to achieve this end. Only when the number of listeners is large is it going to be possible to make effective use of the medium, so the early availability of cheap receivers is crucial to any business plan. The Eureka 147 DAB system has been developed to respect this need and is now accepted internationally as a standard DAB system, and the only one with universal delivery application.

2.3 The Eureka 147 system

This system is a high capacity multiplex which is broadcast on a large number of closely-spaced digital carriers based on COFDM (Coded Orthogonal Frequency Division Multiplex).[3,5] It is designed to operate ruggedly in the presence of low signal strength, multipath interference and Doppler shift caused by mobile reception.

Very early on in the Eureka project, the advantages of being able to use a single system for all types of channel was considered to be a key requirement. Consequently, Eureka 147 DAB is designed to be used on satellites, terrestrially or in a hybrid combination, where a satellite signal is rebroadcast on the same frequency to fill in the signal in places where reception is poor. The system, principally designed as a rugged terrestrial option, is not the optimum that could have been developed for purely satellite use; in its current terrestrially-orientated implementation, it does require more power than some of the options that have been designed specifically for line-of-sight satellite channels.

2.4 Other systems

Other systems being proposed optimise the use of the satellite transponder. This gives improved performance of the satellite, at least for fixed reception, and so lowers the cost to the broadcaster. The unanswered question, at the moment, is whether this reduces the cost sufficiently for listeners to be prepared to acquire two separate receivers – for respective satellite and terrestrial use.

3. SOLIDARIDAD SATELLITES

3.1 Introduction to the Solidaridad satellites

The BBC, in collaboration with Telecomunicaciones de Mexico (Telecomm) and the Instituto Mexicano de Communicationes, carried out DAB experiments in Mexico City using the Solidaridad 2 satellite. It was considered that satellite digital audio broadcasting using the Eureka 147 system would likely be an attractive proposition for many parts of the world where a terrestrial-only service would be impractical. Solidaridad 2 was designed for telecommunications – operating at L-band to and from the mobiles, and K_u-band to and from the earth station. But note that only the K_u-band up-link and L-band downlink (for transmitting the DAB signal earthwards) were used for the DAB experiments and tests (see Fig. 1). The Solidaridad 2 L-band frequencies are just above those designated for DAB (1.452 to 1.472 GHz). The experiments were mainly based on fixed reception using a high gain antenna, but some simple mobile tests were also carried out.

3.2 General description

The two Solidaridad satellites, flights one and two, were launched in November 1993 and October 1994. They have been sited in the geostationary orbit located at 109.2° W and 113° W, giving them an elevation angle of approximately 63° in the Mexico City area. They are principally designed for communications purposes to furnish a diversity of domestic and regional services; so the Effective Isotropic Radiated Power (EIRP) of each satellite is not as high as would be desirable for broadcasting DAB signals directly to the public.

Solidaridad embodies payloads in ‘C’ ‘K_u’ and ‘L’ bands. In particular, the L-band payload has been designed for multicarrier use to provide voice, fax, data and position-reporting to aeronautical, maritime and land mobile commercial services. Transportable or semi-fixed terminals in remote areas of Mexico also use these services.

The satellite performs the conversion between the L-band signals sent and received by the mobile terminals and the K_u-band used by the earth station. Fig. 1 shows that both the forward and return transponders on each satellite are divided into a number of subbands; these are interleaved between the satellites. The subbands are independently controllable with bandwidths ranging from 2.5 MHz to 5.5 MHz. Parts of the band are used by other operators, such as Inmarsat. However, as stated in Section 3.1, for the purpose of the DAB satellite tests, *only* the Forward Link transponder was used, with the L-band signal acting as the DAB

broadcast transmitter; so the bi-directional communication aspect of the satellite (using the Return Link transponder also) was *not* used for the DAB tests – see Fig. 1 for the frequency plans for both satellites.

The preparations for the experiments had included careful examination of the suitability of the Mexican satellites for use with the Eureka 147 DAB signal. Special emphasis was put on parameters such as phase noise, signal-to-noise ratio, transponder gain and the required bandwidth. This information was used to calculate the link budgets and to select the subband considered suitable for the tests; subband one on Solidaridad-2 was chosen.

The DAB experiments were carried out using 1.52915 GHz in the L-band. This frequency was chosen with due consideration to international frequency coordination, bearing in mind that the DAB spectrum has a bandwidth of 1.5 MHz.

3.3 Forward transponder

The Forward Link transponder receives K_u-band signals from the fixed ground station and converts them to the L-band for onward transmission to mobile or semi-fixed terminals. The K_u-band uplink signals, received by the satellite's vertically polarised receive antenna, are fed to the low noise amplifier (LNA) of the K_u-band transponder. The output of the LNA is then equally divided between the K_u-band transponder and the L-band transponder by a hybrid circuit. Three LNA outputs are configured in this way, to provide 3-for-1 redundancy in the receive section of the L-band transponder. The signals for the Forward Link transponder are coupled from the output of the LNA and before feeding the K_u-band receiver, in order to minimise the number of frequency conversions in the K_u/L transponder; thereby maintaining the requirement for frequency precision.

After amplification, the received signal is applied to

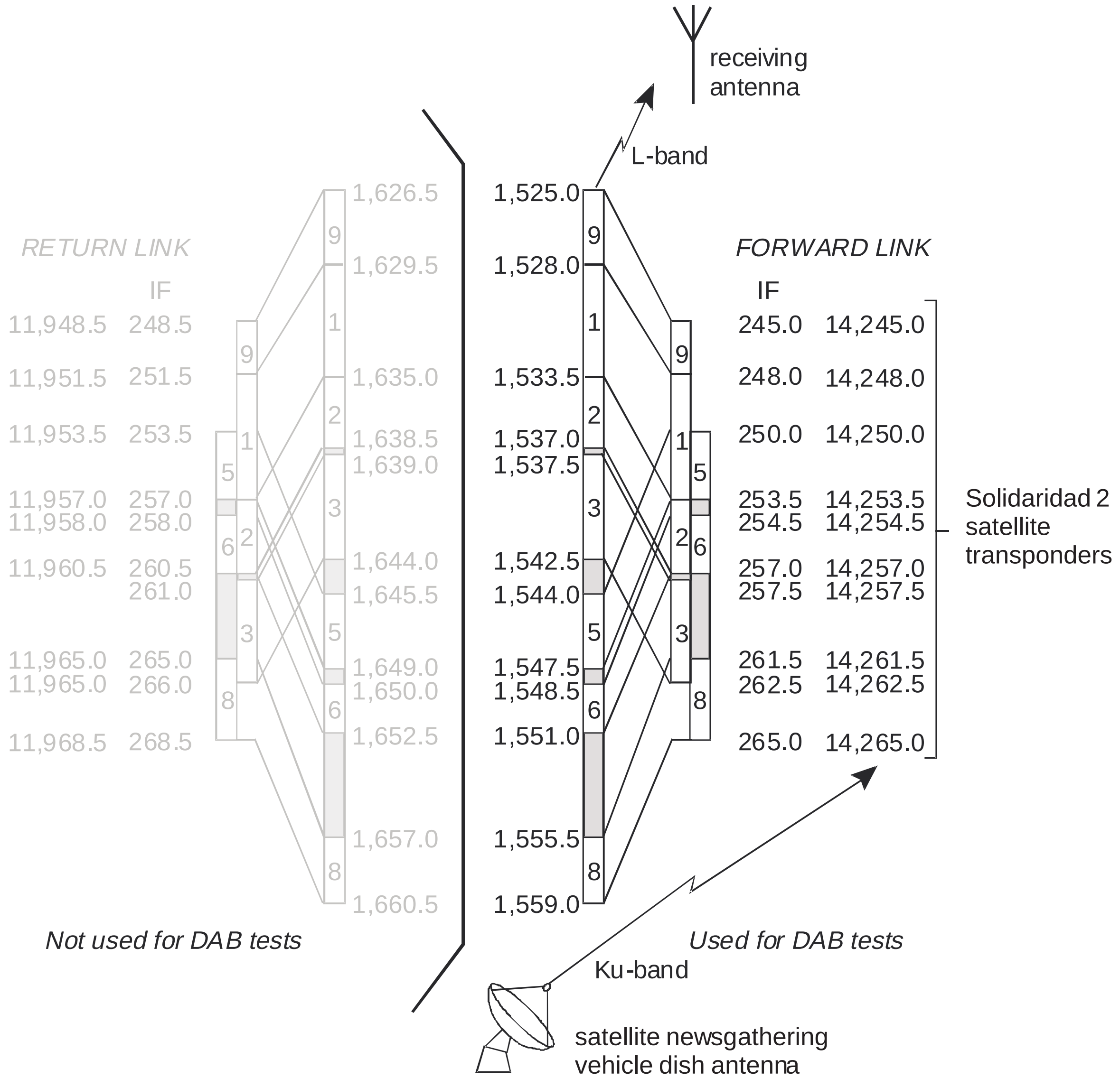

Fig. 1 - Basic frequency plan for the Solidaridad 2 satellite DAB tests.

the input of a 17 MHz bandpass filter, which removes any frequencies destined for the K_u-band transponder. The contiguous 17 MHz band, used for mobile communications, is passed through this filter and then translated to an intermediate frequency (IF) between 245 to 265 MHz by the K_u-band-to-IF downconverter.

The IF-to-L-band upconverters provide channel filtering, channel gain control, and eventual upconversion to the L-band transmitting frequency. Each upconverter contains independent subband filters. Channelisation of the IF signal into the subbands is accomplished with surface acoustic wave (SAW) filters.

Once channelised, each subband signal level may be adjusted independently via the channel control attenuators resident in each IF-to-L-band converter. The control attenuation is achieved by a series of single-step attenuators, which allow a downward adjustment of channel gain over a range of 15 dB from the nominal channel gain in steps of one dB. The subbands in each converter are then recombined and upconverted to the appropriate L-band frequency plan (34 MHz bandwidth). This combined signal is first divided into four separate inputs and fed to a 6-for-4 redundant switch ring of SSPAs (solid state power amplifiers), to be amplified for transmission by four SSPAs operating in phase.

A master reference oscillator, which provides coherent local oscillators for all upconverters and downconverters, is employed in the L-band transponder to ensure compliance with the requirements for frequency translation accuracy during its operational life, and also between each of the subband channels. A 10 MHz crystal reference oscillator has been chosen because of its demonstrated short- and long-term stability characteristics.

4. TEST SYSTEM

The object of the tests was to verify that the Eureka 147 system is suitable for satellite transmission. In particular, it was hoped to measure the link margins for both static and mobile reception. The experimental system used is outlined in Fig. 2. Two separate sources of stereo audio from two CD players were each Musicam-coded; usually one at 256 kbits/s and the other at 224 kbits/s (one of the feeds was buffered and taken off to be fed directly to the receiving equipment for A-B comparisons to be made). The two stereo feeds were then multiplexed into the first two slots in the Eureka 3rd generation fixed multiplex. The signal was then COFDM-modulated and converted to an intermediate frequency of 70.15 MHz, for transfer to a satellite newsgathering (SNG) vehicle (shown in Fig. 3) provided by Telecomm, via an attenuator to set the uplink level. The uplink was in the K_u-band, such, that it was translated by the satellite transponder to 1.52915 GHz (L-band) for broadcasting. This was chosen because a bandwidth of at least 1.7 MHz was needed, which meant that it had to be outside the band used by Inmarsat. The uplink site was the Telecomm Earth Station in Mexico City.

For convenience, the receiving equipment, outlined in Fig. 4, was set up adjacent to the uplink equipment. A yagi antenna of about 1 metre in length (see Fig. 5 *(page 6)*), modified prior to the tests to receive circular

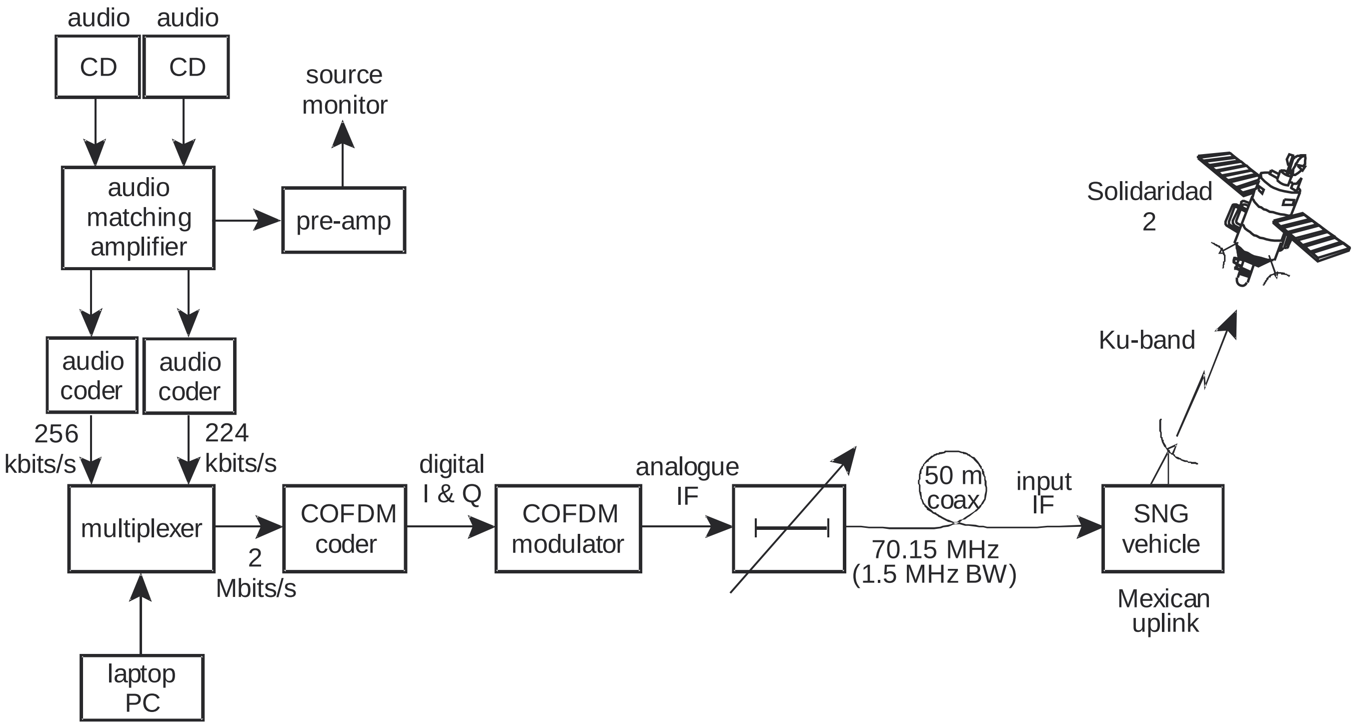

Fig. 2 - Outline of the experimental transmission equipment.

Fig. 3 - The satellite newsgathering vehicle at the Telecom ground station, Mexico City.

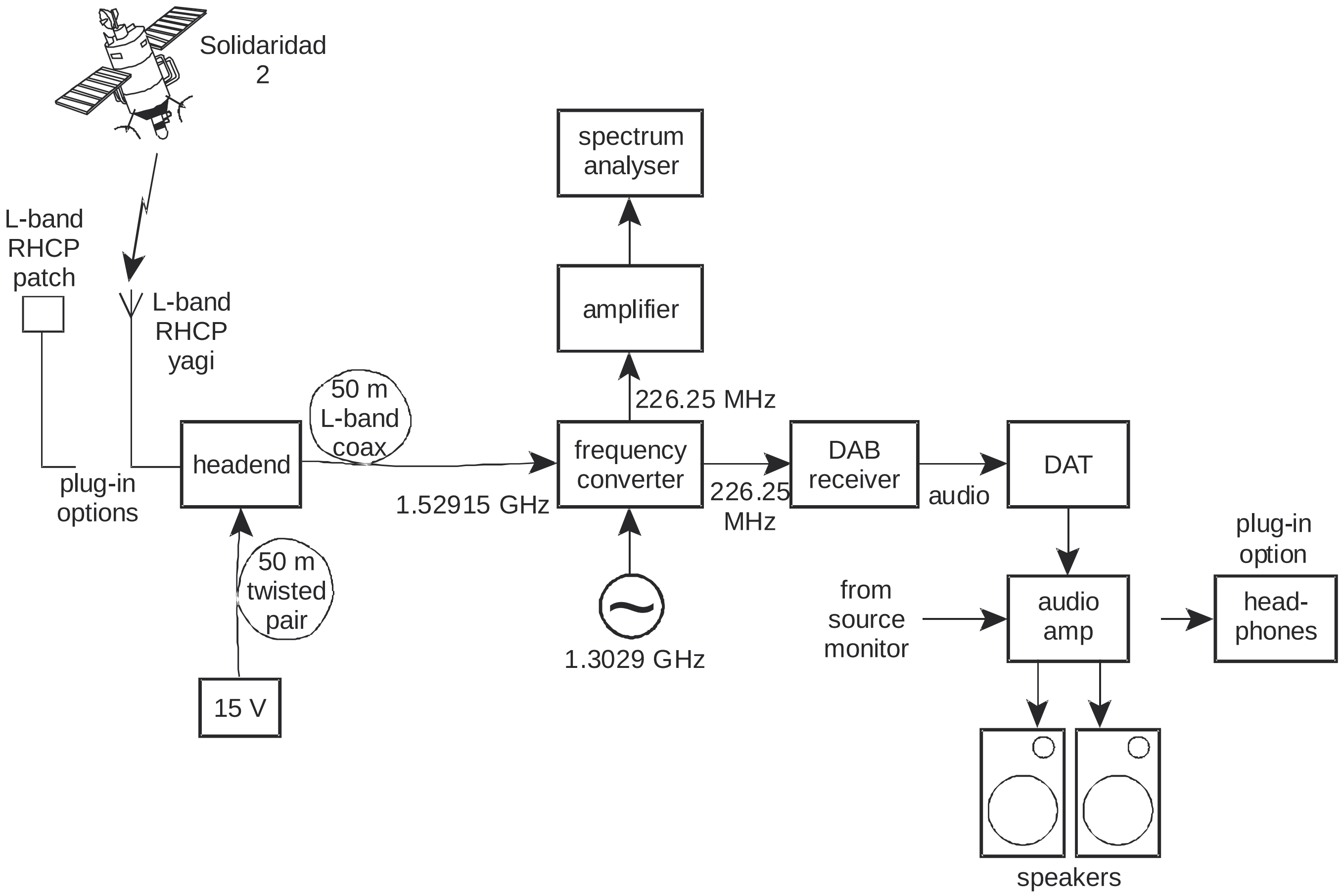

Fig. 4 - Outline of the experimental receiving equipment.

Fig. 5 - The encapsulated Yagi receiving antenna (necessary to receive the low-power satellite signal) and associated headend.

polarisation, was used for the fixed tests; while for the mobile tests, a patch antenna of about 18 cm diameter was used (see Fig. 6). The gains of the fixed and mobile antennas were 14.5 dBi and 8.3 dBi respectively, each to an accuracy of ±1 dB as measured at the National Physical Laboratory, in the UK. The antennas were located outside so as to have an unobstructed view of the satellite. The yagi antenna enabled sufficient signal to be collected to determine the influence of the satellite systems on the DAB signal; the patch antenna is more appropriate for normal use.

The signal from the antennas was immediately amplified by a headend unit (as shown in Fig. 5) which also contained an L-band filter (with 2 dB insertion loss). The signal was then sent through 50 m of low-loss cable to the rest of the receiving equipment located indoors and was initially converted down to Band III. Then it was split, with one half feeding a Philips 452 test receiver and the other half being further amplified for display on a spectrum analyser. The audio signal from the receiver was played through loudspeakers (as could the *direct* feed of one of the audio sources mentioned above) and also recorded on Digital Audio Tape (DAT).

Fig. 6 - Patch antenna being fitted to the roof of the pick-up truck.

For the mobile tests, most of the equipment could be powered directly from 12 V. The exception was the Marconi synthesiser which had to be powered via an inverter. In the mobile tests, the signal was monitored on headphones as well as being recorded.

5. EXPERIMENTAL RESULTS

The experiments were carried out at each of the three DAB transmission modes; Mode I (1536 carriers, 1 kHz spacing), Mode II (384 carriers, 4 kHz spacing) and Mode III (192 carriers, 8 kHz spacing). Only Mode III has been specifically designed for L-band satellite operation, so it was interesting to see how well the other modes performed. The performance indicator used was the bit error rate (BER) before Viterbi decoding (no error rate measurements were made after error correction). The BER reading was readily available from the Philips 452 test receiver that was used, as it had been found to be a sensitive measure of audio quality. Measurements of the satellite Effective Isotropic Radiated Power (EIRP) were relayed from the satellite control centre located in a building near to the test site.

5.1 Back-off tests

The back-off measurements were carried out by varying the signal level uplinked to the satellite and then measuring the BER while noting the uplink power and the satellite EIRP. The maximum permissible EIRP was 43.5 dBW, this is short of the maximum possible (47 dBW) as the operators were being cautious regarding the effect that the DAB signal might have had on the satellite transponder. Fig. 7 shows the results obtained, where the 'threshold' indicates the point at which bit errors produce audible impairment of the received audio signal.*

The differences in performance between the three modes of operation can be seen to have been very small, but there is a noticeable increase in power penalty of about 1 dB between modes I and II. The most likely reason for this could have been the possible presence of phase noise in the upconverter oscillator used in the SNG vehicle that did the uplinking – the satellite on-board oscillator was known to have excellent performance. The slight increase in the scatter which shows in the results of modes I and II can be correlated with the presence of dense storm clouds during that part of the tests. Although the L-band downlink should not be affected by rain attenuation,

∗ The impairment was audible under non-critical listening conditions.

this is not the case for the K_u-band uplink (which was cosited); also, there is the associated change in sky noise temperature (i.e. background cosmic noise).

The results of L-band back-to-back tests, carried out by BBC R&D at its UK Kingswood Warren headquarters' site beforehand, are also plotted in Fig. 7. They indicate that there is a power penalty when using the satellite system. However it is the difference in slope that is of main interest, showing that even in mode III there is still a residual effect from the uplink and satellite which increases slightly with power. It is not clear whether this effect is due to oscillator phase noise, amplifier non-linearities or other causes.

Fig. 8 shows the variation in the uplink High Power Amplifier (HPA) output against satellite EIRP, from which it can be seen that the satellite transponder is linear. This is as expected because the transponder incorporates linearizing circuits for multi-user operation.

5.2 Power budget

The power budget can be checked from Fig. 7 by taking the satellite EIRP which crosses the threshold of impairment; this value is 37.5 dBW for Mode III. Table I *(overleaf)* demonstrates the link budget for this system. At 37.5 dBW transmitted power, a C/N of about 7.8 dB could be expected. Previous tests[2] indicate that at this C/N a BER of about 3×10^{-4} should be observed after error correction (4×10^{-2} is obtained before error correction). Additional differences may be caused by the phase noise of the oscillators, but this should account for significantly less than 1 dB of the difference. There may also be inaccurate assumptions about the figures assumed for sky noise. Under these conditions, the results are close to those predicted.

Another way of assessing the power budget was by operating the satellite at high power (43.5 dBW) and inserting an attenuator between the high gain receiving antenna and the headend amplifier. The insertion loss of the attenuator with its extra lead was about 1.2 dB. Fig. 9 shows a graph of the measurements; from which it can be seen that the curve crosses this threshold at an attenuation of about 2.0 dB. However, the actual margin is greater than the 3.2 dB implied due to thermal noise introduced by the attenuator.

Table II *(overleaf)*, following, shows the power budget obtained with the attenuator set for operation at the threshold point. This power budget also includes an extra 0.8 dB on the C/N to compensate for the distortion of the DAB signal at high power; as shown by the increased separation of the Mode III and back-to-back curves in Fig. 7. Note that the G/T has been modified to take account of noise introduced by the attenuator.

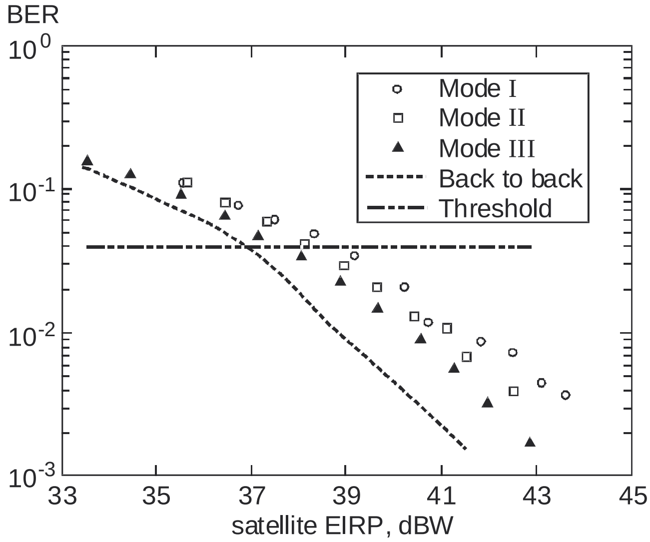

Fig. 7 - Bit error rate against satellite power.

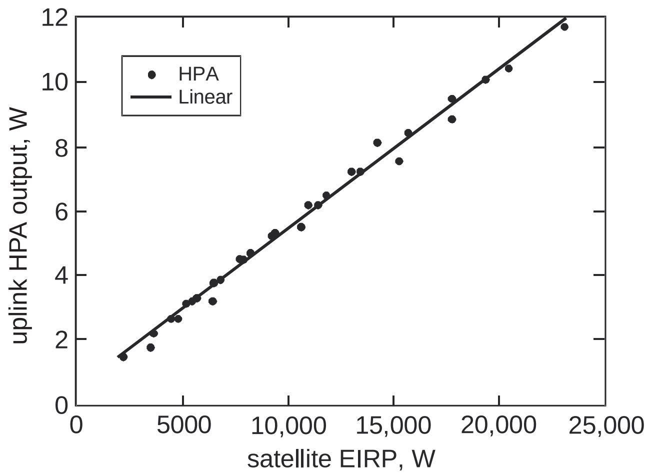

Fig. 8 - Satellite transponder input/output characteristic.

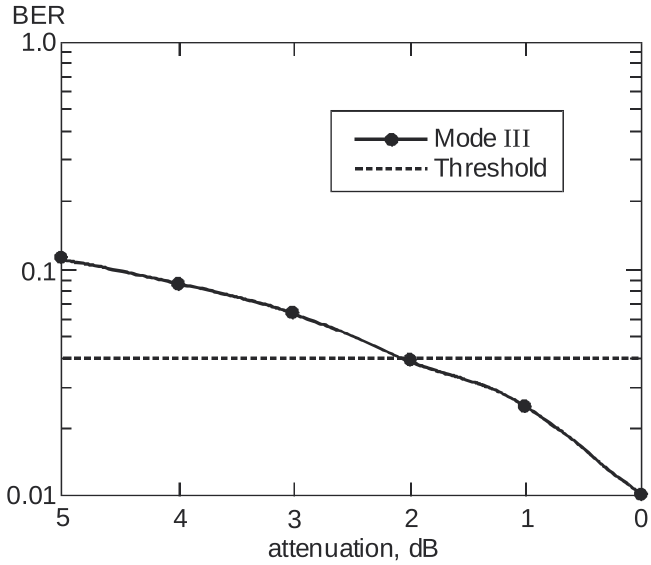

Fig. 9 - BER against received signal attenuation.

By comparing Tables I and II, the true power margin can be seen to be 6 dB using the high gain (yagi) antenna and with the satellite transmitting at 43.5 dBW.

Table I:
Solidaridad power budget for DAB reception.

Satellite EIRP	37.5 dBW
Spreading loss	–163.0 dB
Received signal	–125.5 dB(W/m^2)
Effective area of isotropic antenna	–25.0 dB(m^2)
Receiver G/T	–8.5 dB/K
Boltzmann's constant	+228.6 dBJ/K
Bandwith	–61.8 dBHz
Received C/N	7.8 dB

Table II:
Power budget for DAB reception with an attenuator.

Satellite EIRP	43.5 dBW
Spreading loss	–163.0 dB
Received signal	–125.5 dB(W/m^2)
Effective area of isotropic antenna	–25.0 dB(m^2)
Receiver G/T	–10.7 dB/K
Boltzmann's constant	+228.6 dBJ/K
Bandwith	–61.8 dBHz
Attenuation	3.2 dB
Received C/N	8.6 dB

Table III:
Solidaridad power budget for mobile DAB reception.

Satellite EIRP	43.5 dBW
Spreading loss	–163.0 dB
Received signal	–125.5 dB(W/m^2)
Effective area of isotropic antenna	–25.0 dB(m^2)
Receiver G/T	13.2 dB/K
Boltzmann's constant	+228.6 dBJ/K
Bandwidth	–61.8 dBHz
Margin	0.5 dB
Received C/N	8.6 dB

During these tests, it was not possible to see any increase in intermodulation products (IPs) within the limits of the received signal-to-noise ratio. The IP level could be expected to be low because the SNG uplink was operating a 300 W TWT high power amplifier (HPA) at well below its maximum output power (at about 10 W), and also the HPA on Solidaridad satellite is equipped with linearizers; though there is the unexplained 0.8 dB power penalty at high power.

5.3 Mobile reception

A pick-up truck was equipped to receive the satellite DAB signal from a patch antenna mounted at 63° on the roof using a magnetic base (Fig. 6). This antenna had a measured gain of 8.3 dBi and a 3 dB beamwidth of about ±35°. The receiver was found to be operating just within threshold at a BER of between 2 to 4 × 10^{-2} when the vehicle was stationary and the satellite was operating at an EIRP of 43.5 dBW. Table III shows the mobile power budget, confirming that the operating point was indeed close to threshold:-

It was clear that the mobile tests would have to be performed with the vehicle travelling in a straight line, in order to keep the antenna orientated correctly to receive the signal. A series of measurements of BER against velocity were recorded as the vehicle drove south along a roadway within the Telecomunicaciones de Mexico (Telecomm.) compound. Tests were carried out at velocities of 15, 30, 45 and 60 km/hr in each of the three DAB modes; the maximum speed was limited by the length of the roadway and by necessary safety considerations. The measured BER was within the range 3 to 5 × 10^{-2}, and did not depend on vehicle speed. However, a slight increase in BER was sometimes recorded during the acceleration period, but a firm correlation could not be proven within the limited acceleration capabilities of the vehicle used for the tests. One test was carried out with the vehicle driving in the opposite direction, but no differences in results were noted.

The component of the vehicle's velocity in the direction of the satellite was about half its road speed due to the high elevation of the satellite (63°). Thus, at the highest speed of 60 km/hr, the Doppler shift was 38.6 Hz which can be accommodated even in Mode I – which has the closest carrier spacing. It is important to note that these experiments have not tested the system performance under conditions of differential Doppler shift caused by the presence of signal reflections (multipath); a higher power satellite would be needed for such tests, which should also include measurements at motorway speeds.

The vehicle was driven through the suburban streets of Mexico City for about 40 minutes at speeds of around 40 km/hr in order to qualitatively assess the reception. Because the antenna needed to be kept manually aligned with the satellite, it was not always possible to ensure that optimum alignment was maintained. However, some interesting observations were made:

- It was found that when the antenna was correctly aligned on the satellite, and that there was a clear unobstructed view, then good reception down to a BER of about 3-5 × 10^{-2} could be obtained.

- Any shadowing, e.g. by buildings, bridges and trees, caused the signal to be lost for that moment. It is, therefore, clear that there was insufficient power margin to test the capability of the DAB receiver for making use of reflections.

- A simple test of indoor reception of satellite DAB for portable receivers was carried out through the window at the satellite earth station. But it was found that there was insufficient power available to receive a usable signal on the lower gain patch antenna.

6. DISCUSSION

These tests have shown that satellite broadcasting of DAB is feasible, even in Mode I, if the satellite elevation is high enough to reduce the Doppler shift of any reflections. The Solidaridad transponder has linearizer circuits which keep the IPs to low levels, although about 0.8 dB of power penalty did occur under high power operation. The slight differences in the reception quality that did occur between the modes is most likely to have been due to residual phase noise in the equipment of the SNG uplink vehicle used; if so, there would be scope to have a better performance from a specially designed uplink.

It is possible, though, to make a first-cut estimate of the requirements for a practical satellite DAB broadcasting system to mobiles from a geostationary satellite, assuming:

- that mobile reception requires a non-steerable antenna with an omnidirectional gain pattern in the horizontal plane, this (along with mass production considerations) means that the antenna gain will probably be about 4 dBi;
- that the fade margin required to cope with shadowing is 6 dB (and this may cause additional noise from the environment);
- that 0.2 dB margin is required for rain attenuation (contributing some noise);
- that 1 dB margin is required for system penalties (partially contributing noise).

Table IV:
Estimated power budget for a satellite DAB service.

EIRP at edge of service	55.2 dBW
Subtract:	
Attenuation at L-band	187.4 dB
Receiver C/N required	8.0 dB
RF bandwidth occupied	61.8 dBHz
Rain	0.2 dB
System penalty	1.0 dB
Noise temperature	22.6 dBK
Distortion penalty	0.8 dB
Add:	
Boltzmann Constant	228.6 dBJ/K
Antenna gain	4.0 dBi
Fade margin	6.0 dB

Table IV shows that the satellite EIRP, as seen from the edge of the service area, needs to be 55.2 dBW. The satellite power could be reduced by minimising the system penalties and the distortion.

A satellite with a high power transponder will be needed for the next stage of mobile reception tests in order to fully explore the ability of the Eureka 147 system to make use of reflections from buildings. Such a high power transponder would also allow indoor reception experiments with portable equipment to be made.

7. CONCLUSIONS

Tests of satellite DAB broadcasting in the L-band from the Solidaridad 2 geostationary satellite, covering Mexico, confirmed that the Eureka 147 DAB system is suitable for use in satellite broadcasting.

Neither the satellite nor the uplink significantly affected the DAB signal.

It was possible to use Mode I, which is not intended for use above 375 MHz. There was just sufficient power received to allow tests of mobile reception to be carried out. This showed that Doppler shift was not a problem at road speeds of up to 60 km/hr with a geostationary satellite (which appeared at high elevation in Mexico).

It has been possible to estimate from these tests the aggregated power required for a satellite broadcast service to mobiles. These early results obtained from the use of higher transmission powers clearly indicate that further tests are required to discover what value signal reflections may have for mobiles passing through cluttered streets. Such tests would also be needed to examine the possible use of reflections for fixed installations which were located in areas where satellite signals were shadowed by high-rise buildings or steep terrain.

8. ACKNOWLEDGEMENTS

The authors thank colleagues at Telecomunicaciones de Mexico and the Instituto Mexicano de Comunicaciones for the use of the Solidaridad 2 satellite, the earth station facilities, test equipment and their enthusiastic help given during these tests.

9. REFERENCES

1. LEE, M.B.R., 1993. Planning methods for a national single frequency network for DAB. Proceedings of International Conference on

Antennas & Propagation, IEE Conference Publication No. 370, pp. 970-947.

2. ITU-R Special Publication, 1995. Terrestrial and Satellite digital sound broadcasing to vehicular portable and fixed receivers in the VHF/UHF bands, Geneva.

3. ALLARD, M. *and* LASSALLE, R., 1987. Principles of modulation and channel coding for digital broadcasting for mobile receivers. EBU Technical Review No. 224, August, pp. 168-190.

4. ITU-R Recommendation BO. 789, 1994. Digital sound broadcasting to vehicular, portable and fixed receivers for BSS (sound) bands in the frequency range 500 – 3,000 MHz. March.

5. SHELSWELL, P., 1995. The COFDM modulation system: The heart of digital audio broadcasting. *Electronics & Communication Engineering Journal*, **7**(3), June, pp. 127-136.

Published by BBC RESEARCH & DEVELOPMENT DEPARTMENT, Kingswood Warren, Tadworth, Surrey, KT20 6NP